A Direct Deformation Method

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[Abstract] This paper presents a new free form deforming interface named Direct Deformation Method (DDM). DDM allows designers to touch and deform free formed surfaces directly, at any point of the surfaces, even if they are represented only by control points and knot vectors. Users do not need to know about such parameters that represent surfaces. The deforming actions of a user are used to calculate new parameters that define the deformed shape of the object. The shape is then reconstructed using the new parameters, allowing the user to visualize his or her deformation. This technique is easy to apply and useful for various form representations.

1. Introduction

Today's CAD (Computer Aided Design) interface has two large problems in manipulating tree dimensional (3D) free forms [Fari88]. The first, designers should deal free forms with 2D equipment, for example, CRT displays and mice. It is hard to recognize 3D free forms on 2D displays. Fortunately, virtual reality (VR) is a promising technology to solve this problem. VR technologies will provide users with realistic truly 3D free form images and I/O devices in the near future.

When 3D interface devices are improved, the second problem will arise; That is the indirect free form handling method. Most of the existing free form deformation methods are indirect ways. Users can not touch surfaces directly, but some special parameters called control points, weights, and so on. Designers are forced to deal only with those parameters to alter forms they are designing. The more VR technology advances, the more this indirection will cause designers a serious frustration that they can not touch what they see. A method to deform free forms directly is strongly needed.

This paper presents a new direct form deforming technique named Direct Deformation Method (DDM). DDM is a novel interface that allows users to touch and "push" anywhere on surfaces to alter forms, even if they are defined only by control points and knot vectors. It is a simple, but effective technique, that can also be applied to simpler figures, e. g. arcs and polyhedra.

2. Review of Existent Form Deformation Technologies

Existent free form deformation methods can be categorized into tree groups: indirect deformation, physically-based simulation, and local geometry manipulation.

(1) Indirect deformation

Most of all deforming methods are indirect; Users can not touch a surface itself, but some special parameters, such as, control points and weights. A surface can be deformed only via those parameters. The Free-Form Deformation [Sede86], function based deformations [Barr84, for example], and implicit surface modeling [Blin82 etc.] can also be categorized in this category. Problems of this deformation type are:

a. Parameters that designers can utilize differ according to surface representations. Users should learn how many kinds of parameters they have on their CAD systems.

b. Different kinds of parameters have different effects in deformation. Designers should learn deforming effects of each kind; moreover, they should always determine which parameters and how much change should be made to alter shapes correctly. It is useless to waste their creativity on such non essential work.

c. Indirect deformation is unnatural. The more VR technology proceeds, the more natural and direct deformation interface will be needed.

(2) Physically-based simulation

Several deformation methods simulate physical features of real materials, such as, elasticity and volume preservation [e.g. Terz88] and are often used in animations and VR techniques that feedback appropriate forces to users. From the standpoint of interactive design, these methods have following problems:

a. Calculation time of physical features is too long. It can be shortened if the granularity of deformation is coarser; they are trade-offs.

b. Physical features may be obstacles to form design. For example, elasticity is not needed in design that is an essentially inelastic deformation process. Volume preservation will give both desirable dents of shapes and undesirable rises.

(3) Local geometry manipulation

[Geor91] proposed a new surface deformation method that directly manipulates surface geometries, such as, tangent vectors and curvature, at any point of a curved surface. The method is independent of surface representations and provides an interactive deformation environment. It must be a good tool for local and minute deformation, however, it has two weak points.

a. Deformation of wider range is difficult.

b. It forces designers to translate their form image into surface geometries. Human visual cognition system has a famous phenomena called "illusion," which plays an important role in form design. For example, a plane is not a plane for our eyes. When we see a geometrically true plane, we feel as if its center is slightly dented. To avoid giving such a strange impression, designers do not use true planes, but slightly swelled surfaces instead. Can designers describe such 'swell' geometrically?

3. Formulating DDM

3.1 Formulation of DDM

The basic idea of DDM is that when a cursor (a mouse cursor, a pen, a finger position, etc.) performs a deformation action to shapes (e.g. pushes a shape), parameters that represent the shapes are changed automatically so as to deform shapes appropriately to the deforming action. If the deformation is fast enough, the technique allows users to observe the effect of deformation is directly caused by the "pushing action" of the cursor.

The following is a detailed description of DDM. For simplicity, a 2D B-Spline curve of degree 3 is used as an example free form representation, though, DDM can be easily applied to 3D free forms and other shape representations.

Figure 1 shows the principle of DDM. The original curve segment C shown in the solid curved line is deformed into C', the dotted curve, according to the following algorithm.

(1) Track a cursor coordinate $M(x, y)$ and check whether it crosses the curve C. If it does, then go to #2 process.

(2) Change parameters that represent C, or control points $\{V\}$ and its knot vector $\{t\}$, to deform the curve according to the crossing motion of the cursor.

V_i, ..., V_{i+m}: Corresponding control points of C,

m: An integral number, equal to or more than 0,

$\{t_k, ..., t_{k_1}\}$: Corresponding knot values of C,

m_0: Mouse cursor location before crossing C,

m_1: Mouse cursor location after crossing C,

P: The point where the cursor crosses C,

w_i, ..., w_{i+m}: Weights of V_i, ..., V_{i+m}
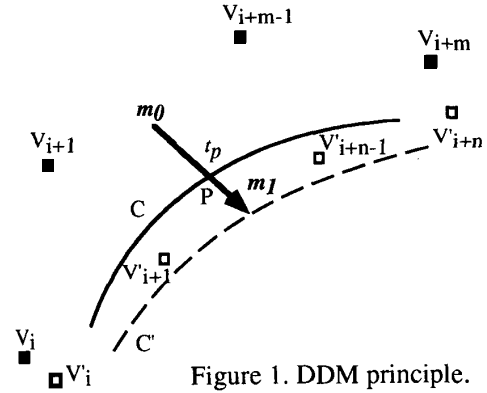respectively at P, and

t_p: Knot value at P.

Figure 1. DDM principle.

New control points $\{V'\}$ and new knot vector $\{t'\}$ are calculated according to a *deforming function* F as follows:

$$\{\{V'\}, \{t'\}\} = F(\{V_k\}, \{w_k\}, m0, m1, \{t\}, t_p) \qquad \text{(Eq. 1)}$$

where k = i, i+1, ..., i+m.

The only condition that function F must satisfy is:

[Condition 1] C' and vector $m_0 m_1$ do not cross each other, or both coordinates m_0 and m_1 are on the same side of C'.

Note that not only parameter values but element numbers of $\{V'\}$ and $\{t'\}$ may be different from original ones.

(3) Display the new curve C' and return to #1.

3.2 Basic Characteristics of DDM

(1) Deforming function F provides various kinds of deformations including deformations equivalent to form-defining parameters' change. In Eq. 1, for example, if m=0 then the deforming effect may be equal to moving the nearest control point to the cursor. If m > degree of C, then wider curve segment will be deformed by one pushing action. You can insert new knots and control points that enables you to deform narrower area.

(2) Man-machine interface in deformation is independent of form representations. Users are free from form-deforming parameters.
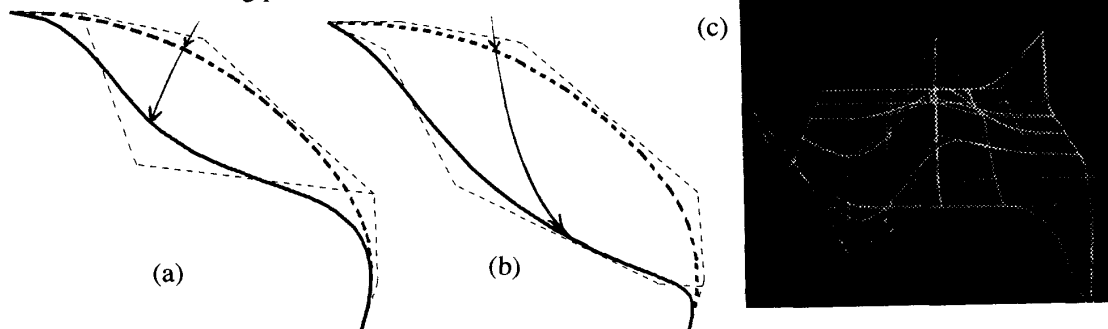
Figure 2. Effect of DDM. (a) One control point is moved at the same time, (b) Four control points are moved at the same time, and (c) 3D surface deformation.

4. Implementing DDM

4.1. Direct Deformation of Free Forms

A DDM system, that employs Non-Uniform B-Spline curves of degree 3 and Non-Uniform bicubic B-Spline surfaces as its form representation, has been implemented on our IRIS Indigo. In Figure 2, original curves, shown in thick dotted curves, are "pushed" by cursors (thin solid lines) and deformed into thick solid curves. Based on the DDM principle described in chapter 3, new control points {V'} are calculated as follows:

$$V'_j = V_j + a \cdot w_j \cdot (m1 - m0)$$

where   a : Positive real number and

k = i   (Figure 2. (a))

i, i+1, i+2, i+3   (Figure 2. (b))

In this system, only control points are changed. Positive number a is determined each time so as to satisfy the Condition 1 with an algorithm similar to binary search. The algorithm gives an effect that the cursor "slips" on the form. Note that the system does not solve the inverse function of spline. The method is basically the same in 3D deformations.

4.2. Additional Direct Deformation Primitives

Three additional deformation primitives, which are fixed point, straight line, and angle, are also implemented on the system. These are for 2D curves only now. 3D version is under construction.

(1) Fixed Point (Figure 3)

[Interface] Click a mouse button on a form, then the point becomes fixed.

[Implementation] First, insert as many knots as degree of the curve at the selected point without changing the form. To make the point fixed, fix three control points, the control point coincident with the point and its two neighboring control points, not to be moved by the deformation. Then the selected point becomes free from deforming action and C^2 continuity at the point is guaranteed.

(2) Straight Line

[Interface] Select a part of a curve and push a button. Then the selected part becomes straight .

[Implementation] Control points that construct the selected part are arranged in a straight line. The straight part can be easily deformed again.
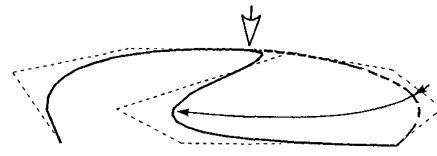

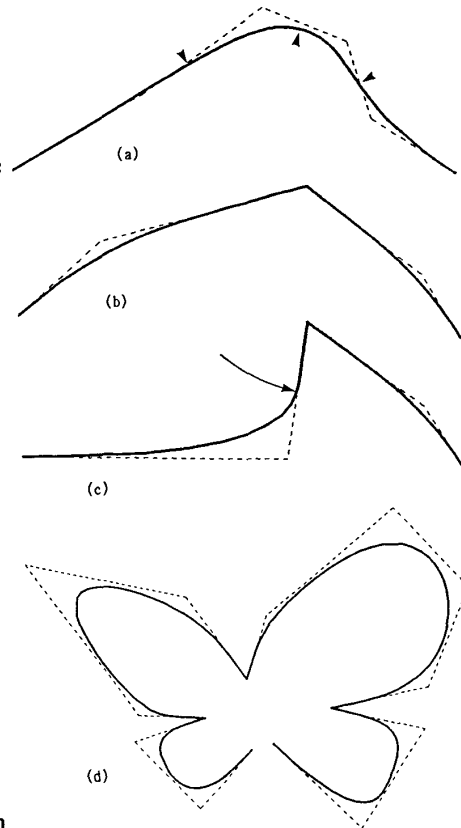Figure 3. Effect of direct deformation does not exceed a fixed point.

Figure 4. An angle. (a) The original curve, (b) an angle is formed, (c) the lengths and the angle of line segments can be controlled, and (d) an example artwork using angles (takes about 3 minutes).

(3) Angle (Figure 4)
[Interface] Select a part of a curve and a point on the part. An angle appears when the button is pressed. The angle and the curve are smoothly connected. Users can alter its position, angle, and lengths of line segments directly through pushing and grabbing.
[Implementation] An angle is constructed with a cusp and four control points that form straight line parts.
(4) Rotation (Figure 5)
DDM can also be applied to manipulating other form representations. Figure 5 shows an example of rotation.
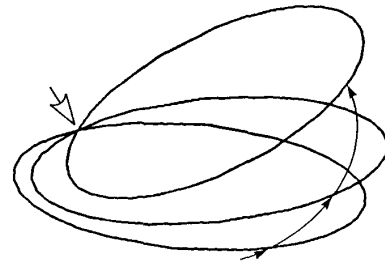

Figure 5. An ellipse is rotated by the "pushing" of a cursor. The arrowhead is the centre of the rotation.

5. Discussion and Future Work

Compared to existing form deformation methods, DDM and its implementation offers following merits:

· More natural and easier form deformation interface. Shapes are smoothly and rapidly deformed as much as a cursor's push. It is easy to mould the same shape as the trail of designer's hand. The real ability of DDM will be exhibited when it is combined with a 3D input device with force feedback [Fuku91].

· Independence of form representations. DDM does not require any knowledge about how shapes are represented mathematically, or, what parameters they have to alter forms. It also means that DDM can be applied to many kinds of form representations.

· DDM does not exclude existing deformation methods. Users can select any technique they like.

DDM's deforming function (see Eq. 1), that involves various kinds of deformations, has the following problems:

· What kind of deforming functions should be prepared?
· How to select a set of desirable deforming functions?
· Realization of deformations with topological change, such as, digging holes and fusing objects together.

These problems can be solved by "tool metaphor," that is the system prepares special tools for each kinds of deformations and users can select appropriate deformation tools. For example, users can dig a hole with a "virtual drill" that can change topology of forms. "Gesture" will also add much to improve DDM interface, for example, selecting an area to be deformed.

Other future works are:

· Multi-point deformation; Deform an object with two or more fingers simultaneously. It will need a parallel processing for realtime response.
· Evaluation of DDM's usability, or performance, through psycho-physical experiments.
· Evaluation of computing cost of DDM and algorithm improvement.

6. Conclusion

A new direct form deformation method DDM was introduced. With DDM, users can deform free forms by "pushing" them directly with a cursor; Then the shape deformed as much as the "push." Because DDM is independent from form representation, designers do not need to know such parameters as control points. DDM also provides many kinds of deforming functions.

In the near future, DDM will be combined with the 3D input device with force feedback that Dr. Fukui, one of the authors, is developing and increase "touch and feel" in 3D form deforming process.

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